ICESat SPACECRAFT POINTING SUPPORT STUDY GRANT NAG5-7611

FINAL REPORT

July 31, 2000

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INTRODUCTION

The Geodetic Laser Altimeter System (GLAS) mission is designed to measure changes in the elevations of the polar ice sheets. The ICESat satellite will carry the GLAS altimeter, and will have a nominal orbit altitude of 600 km and orbit inclination of 94°. The groundtrack repeat period is 182 days and will be maintained to < 1 km at the equator via routine orbit adjustments. Science requirements for the GLAS mission demand that the laser altimeter be pointed to within 50 meters of a predetermined reference groundtrack. As the actual ICESat groundtrack drifts away from the reference groundtrack, the attitude must be controlled such that the altimeter boresight is pointed, crosstrack, at the reference groundtrack. This orientation may be described by a rotation, θ, about the instantaneous geodetic local horizontal direction vector, which lies in the orbit plane and is oriented in the direction of motion of the satellite. The attitude is further complicated by requirements related to thermal and power considerations for various instruments, spacecraft components, and solar array orientation. In order to keep battery temperatures within the specified operating range, and maintain near normal pointing of the solar array with respect to the sunline direction vector as the orbit processes relative to the sun, the satellite will be oriented in one of four fixed yaw modes. Each of these yaw modes depends upon the angle between the orbit plane and the sunline direction vector; this angle is designated β'. Table 1 shows the satellite yaw angle, Ψ, for a given β' range. The angle Ψ represents a rotation about the satellite z-axis, which points in the geodetic nadir direction; for $\Psi = 0°$ the satellite x-axis points in the direction of motion.

Table 1
ICESat YAW MODE INFORMATION

β' Region	Yaw Angle
$\beta' > 32°$	$\Psi = +90°$
$+32° \geq \beta' > 0°$	$\Psi = 0°$
$0° \geq \beta' \geq -32°$	$\Psi = 180°$
$-32° > \beta'$	$\Psi = -90°$

Operationally, the required attitude information will be determined on the ground using the predicted position of ICESat as determined from the best available set of initial conditions and estimates of the dynamical force model parameters. An initial study by the Colorado Center for Astrodynamics Research (CCAR) in 1997-98 entitled: "GLAS Pointing Study", NAG5-6146, defined an algorithm to compute the required roll angle for ICESat given a set of reference groundtrack points, the predicted ICESat orbit ephemeris, and the predicted set of ICESat subsatellite groundtrack points. Using this algorithm, the rotation angle, θ, is determined for each time step in the predicted ICESat orbit ephemeris file[1]. This angle is then used, along with the yaw angle for a given fixed yaw mode, to compute the quaternion, which represents the attitude of the ICESat s/c relative to the Earth Centered Inertial (ECI) or Earth Centered Earth Fixed (ECEF) frame of reference. The Earth's orientation is based on tables that are periodically updated in MicroCosm and are derived from the IERS data for ΔUT1, polar motion, precession, and nutation. These quaternions are used to generate the target tables that will be uploaded to the ICESat on-board attitude control system (ACS).

In the process of developing the attitude algorithm for ICESat, a number of important issues were identified. These issues directly affect the ability to meet the 10 m crosstrack pointing error requirement. They have been addressed in a two-year study (NAG5-7611) whose results, findings, and recommendations are summarized in this final report. The results that were obtained during Year #1 allowed for the identification of additional tasks to be accomplished during Year #2. This overall effort has aided and will continue to aid the ICESat project in decisions related to spacecraft pointing and mission operations.

ICESat POINTING SUPPORT STUDY GRANT NAG5-7611: YEAR #1 (07/01/1998 – 06/30/1999)

The purpose of the two-year study grant entitled ICESat Spacecraft Pointing Support and designated as NAG5-7611, was to answer questions raised during development of the GLAS roll algorithm under NAG5-6146 in anticipation of a system that can be used operationally. The following objectives were established for year #1:

1. The roll angles generated by the attitude control algorithm must be converted into quaternions to test compatibility with the attitude control system of the ICESat s/c. ICESat Spacecraft Pointing Support – Year 1, Task 1 (*ISPS Y1T1)*

2. Quantify the accuracy of the orbit predictions necessary for successful operation of the attitude control algorithm, then verify that this prediction accuracy can be achieved for the time, beyond the end of a given orbit determination period, needed to complete operations tasks and s/c upload. *ISPS Y1T2*

3. Recommend a procedure for dealing with the variations in topography over the regions of interest. *ISPS Y1T3*

Tasks 1 and 3 were completed by July 1999; results were reported in the status report titled: "ICESat Spacecraft Pointing Support" and dated July 1999. These results, along with the algorithm development accomplished under the original study grant, were also reported in an AAS/AIAA Astrodynamics Specialist Conference paper dated August 1999[2]. Task #2 was carried over and completed during year #2. Table 2 summarizes the status of the study grant tasks at the end of year #1. Details of tasks 1 and 3 accomplishments are described next.

ICESat ATTITUDE ALGORITHM MODIFICATION: Task *ISPS Y1T1*

Based on the ICESat roll algorithm, a program for computing the ICESat attitude quaternions and angular rates, relative to the orbit frame of reference was developed and written using MATLAB. The algorithm performs the following functions:

- Read reference groundtrack information (time, geodetic latitude, longitude)
- Read ICESat orbit ephemeris file (time, subsatellite geodetic latitude, subsatellite longitude, ECEF position and velocity)
- Convert latitude and longitude to ECEF Cartesian coordinates assuming the reference and subsatellite groundtracks fall on the TOPEX reference ellipsoid.
- Compute the ICESat roll angle as a function of time about the local horizontal direction vector
- Compute the ICESat attitude quaternions relative to the ECEF frame of reference
- Transform the ECEF attitude quaternion at each time step to the orbit frame of reference
- Compute the ICESat orbit β' angle
- Compute the yaw angle required for the current β' case
- Compute the final ICESat attitude quaternion

A data file is generated using this algorithm and contains the attitude quaternions, relative to the orbit frame of reference. This data file was sent to Ball Aerospace Technologies Corporation (BATC) for compatibility testing. After only a few iterations CU/CCAR was able to supply the necessary data files with the required format to drive the BATC ICESat attitude simulator.

ICESat REFERENCE GROUNDTRACK TOPOGRAPHY: Task *ISPS Y1T3*

The ICESat attitude algorithm was originally developed assuming that both the reference groundtrack and the subsatellite groundtrack lay on a desired reference ellipsoid (in this case the TOPEX reference ellipsoid). In practice, however, terrain elevations over the Antarctic region can reach nearly 4000 m and neglecting the topography will certainly induce footprint location errors. In order to quantify the equivalent rotation angle errors, which would result from neglecting terrain elevation, the Joint Gravity Project 95E (JGP95E) topographic data file (5′x5′ gridded elevation data) was used to evaluate the terrain elevations corresponding to simulated reference groundtrack latitude and longitude locations.

Table 2
SUMMARY OF ICESat POINTING SUPPORT STUDY GRANT NAG5-7611: TASKS AND STATUS FOR YEAR #1

Task Designation	Description	Status	Description of Additional Related Tasks Completed under Task Designation	Status
ISPS Y1T1	Convert roll angles to quaternions to test compatibility with s/c performance	Complete	Several cases tested using maximum equatorial and orbit inclination offsets	Complete
			Algorithm modified to include additional attitude requirements due to sun-orbit geometry (β')	Complete
ISPS Y1T2	Verify orbit prediction accuracy can be achieved for time needed beyond orbit determination period	In Progress		
ISPS Y1T3	Recommend a procedure for dealing with topography over polar regions	Complete	Algorithm modified to apply JGP95E topographic elevation data over any location	Complete
			Pointing errors due to topographic height quantified for worst case equatorial and inclination offsets	Complete

Figure 1 shows the reference groundtrack superimposed on a geographic plot of the JGP95E topography file. Figure 2 shows the reference groundtrack elevations above the reference ellipsoid over one orbit for the simulated groundtrack used in this study. The Rocky Mountain region, Himalaya region, and the Antarctic region are well defined. The reference groundtrack, which now includes terrain elevation information, was used to compute the new rotation angle, θ. Figures 3 and 4 show the rotation angle over one orbit for two cases: (1) a maximum equatorial offset of 1 km, and (2) a maximum inclination difference of 0.03° in addition to the 1 km equatorial offset. The 0.03° inclination difference is chosen to illustrate the effects of Luni-Solar perturbations on the ICESat orbit. The difference between the rotation angle computed using elevation information and the rotation angle computed assuming zero elevation (above the reference ellipsoid) is also shown. The corrections needed in the case of a 1 km equatorial offset range between –2 arcsecs and +3 arcsecs. For the case of a 1 km equatorial offset and a 0.03° inclination offset, the corrections range between –8 arcsecs and +10 arcsecs.

Figure 1. Geographic plot of the ICESat simulated reference groundtrack and JPG95E elevation information.

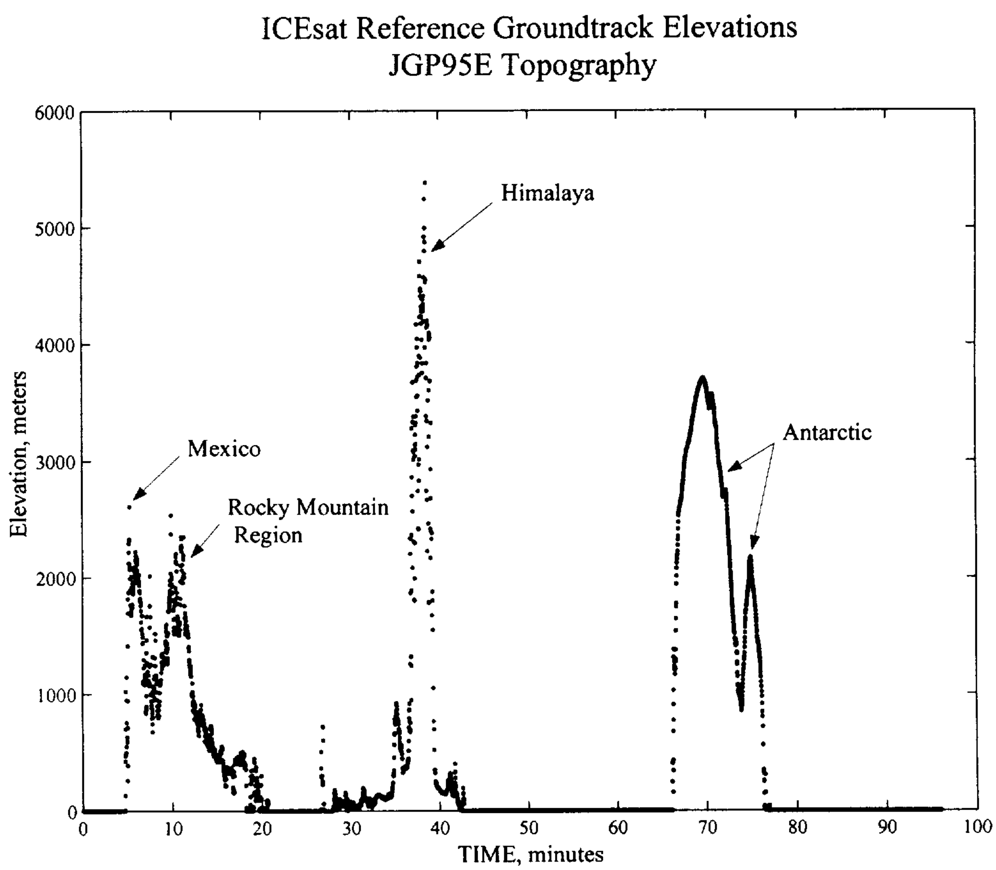


Figure 2. ICESat reference groundtrack elevations over one orbit using the JGP95E topographic

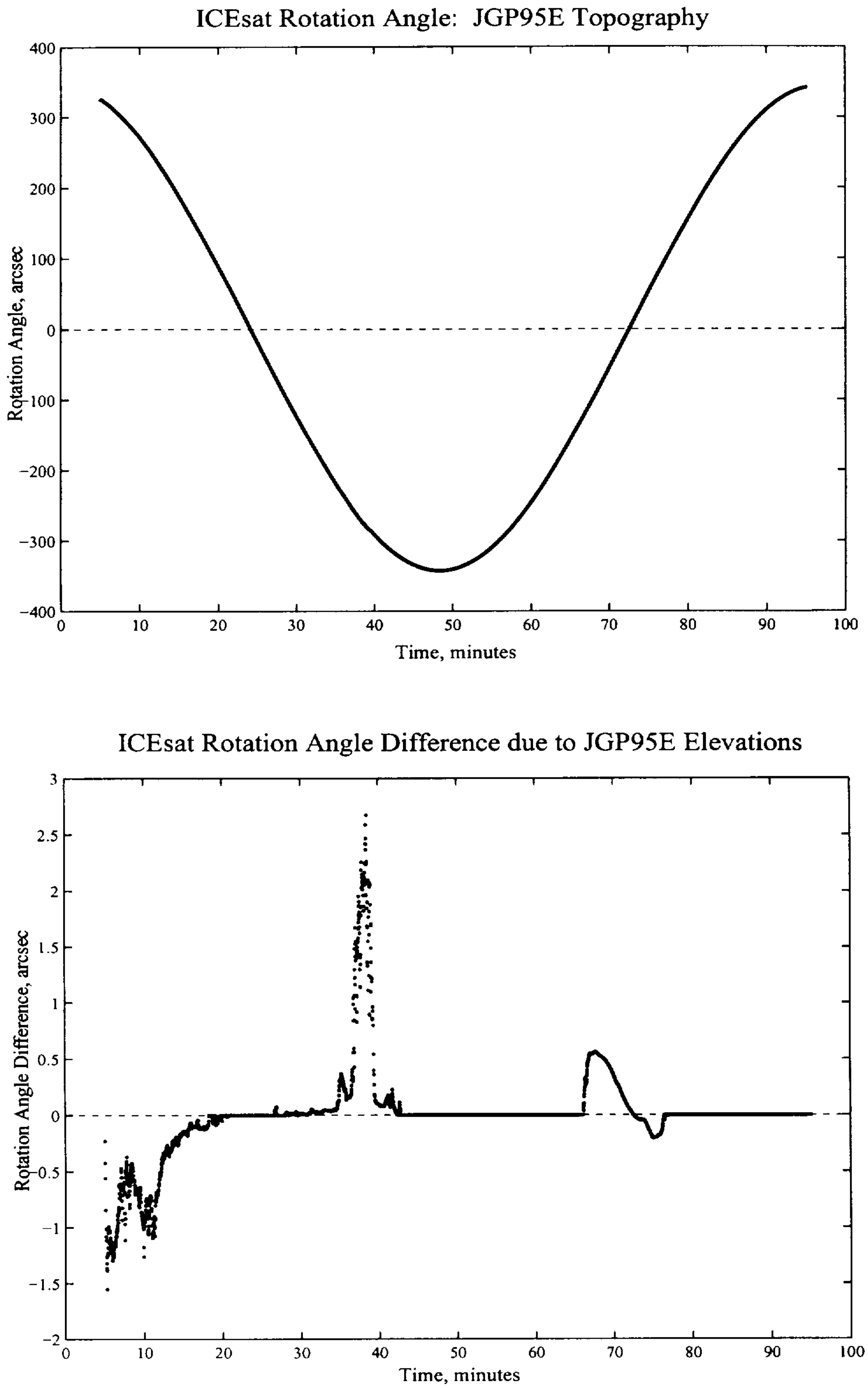


Figure 3. ICESat rotation angle and rotation angle correction due to reference groundtrack terrain information for a 1 km equatorial offset.

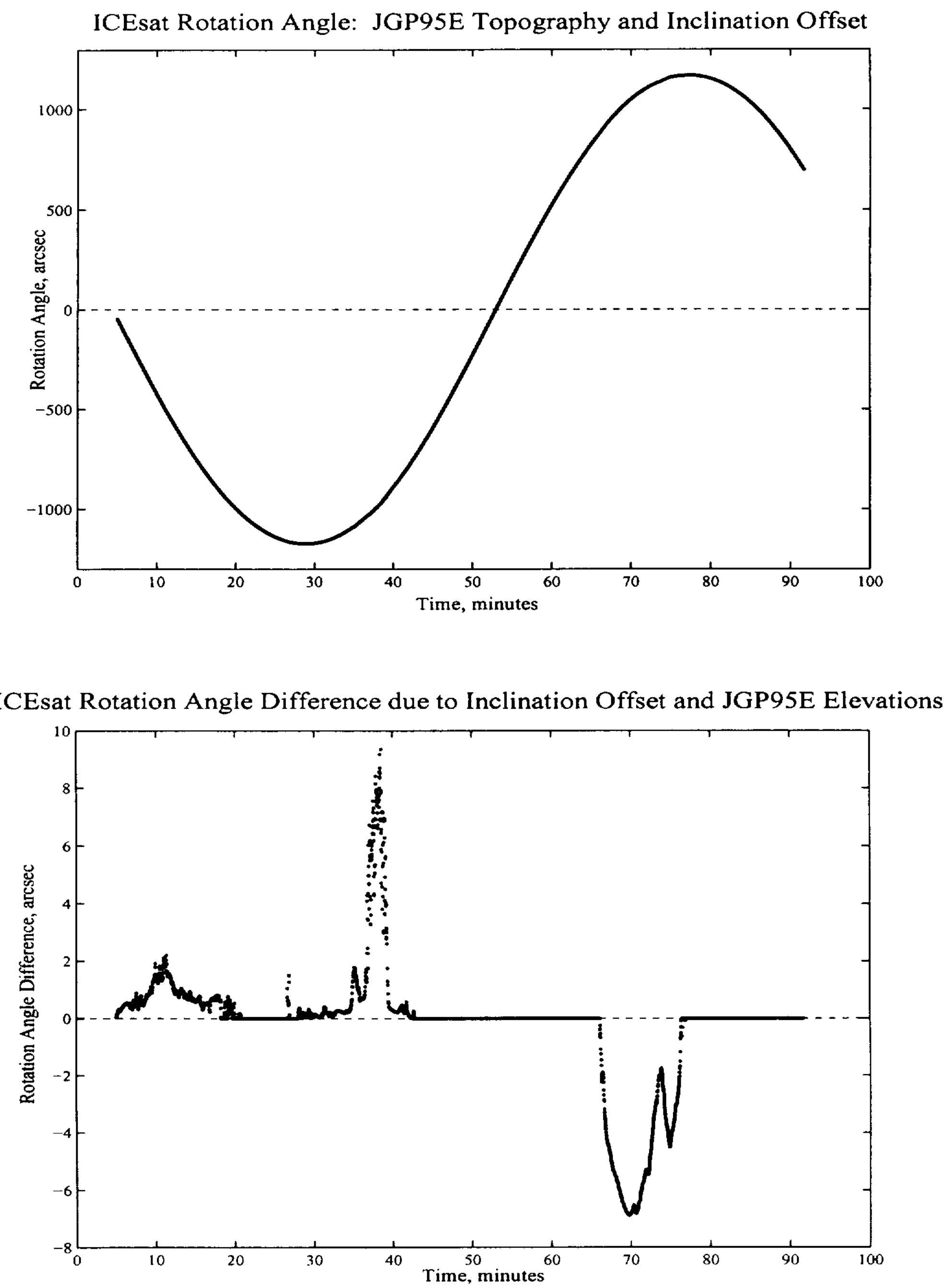


Figure 4. ICESat rotation angle and rotation angle correction due to reference groundtrack terrain information for a 1 km equatorial offset and 0.03° inclination offset.

SUMMARY: ICESat POINTING SUPPORT STUDY, NAG5-7611: YEAR #1

A MATLAB program for generating ICESat command attitude quaternions required to maintain reference groundtrack pointing has been developed and includes the capability to apply topographic heights to a given reference groundtrack. Testing of the attitude algorithm addressed two cases: (1) a maximum equatorial offset of 1 km, (2) a maximum inclination offset of 0.03° in addition to the 1 km equatorial offset. A simulated reference groundtrack was generated using the MicroCosm orbit determination software package. The initial conditions were then adjusted to simulate the case of a 1 km equatorial offset of the ICESat groundtrack relative to the simulated reference groundtrack. A second simulation was performed in which the initial conditions were further adjusted to include the 0.03° inclination offset. The roll angle, θ, required to maintain reference groundtrack pointing ranges in magnitude, between +/- 600 arcsecs during a given day for a 1 km equatorial offset, and between +/- 1400 arcsecs during a given day for a 1 km equatorial offset and 0.03° inclination offset. Results show that neglecting topography can induce a pointing error of as much as 10 arcsecs, worst case; this is equivalent to a crosstrack altimeter footprint location error of approximately 29 m at the surface of the Earth. The footprint location error budget is currently 50 m, of which 10 m is allocated for orbit prediction error and topography variations. Finally, the interface with the BATC attitude command generation software is complete and has been tested using the BATC ICESat attitude control simulator.

ICESat POINTING SUPPORT STUDY GRANT NAG5-7611: YEAR #2 (07/01/1999 – 07/31/2000)

Year #2 tasks were not defined in the original work statement. However, by the end of July 1999, several critical issues were identified by CU/CCAR and the ICESat project for analysis during Year #2:

1. Establish a timeline for the operational orbit determination and command attitude generation process. *ISPS Y2T1*

2. Verification of UT/CSR 8 day repeat groundtrack using operational orbit determination system software. *ISPS Y2T2*

3. Provide recommendations regarding the Amery Ice Shelf as a target of opportunity. *ISPS Y2T3*

4. Modify the attitude control algorithm to compute quaternions relative to the inertial true of date (TOD) frame of reference. *ISPS Y2T4*

5. Determine the number of quaternions necessary to accommodate variations in topography over the polar regions; only 33 quaternions per orbit are allowed, but are not required to be equally spaced in time. *ISPS Y2T5*

6. Verify that the 48-hour orbit prediction requirement of 10 m crosstrack can be achieved for the operational orbit determination and command attitude generation timeline. *ISPS Y2T6*

7. Develop a method for verifying the command attitude quaternions

Tasks 1 through 6 have been completed and the results are presented in this document. The 10 m crosstrack orbit prediction requirement of Task 6 cannot be met with conventional prediction techniques as seen in the results presented below. Alternate methods of meeting this requirement must be developed. Task 7 is an operational task and cannot be done effectively until the automated operational attitude pointing system is developed. Task 7 will be addressed under a separate contract between CU/CCAR and BATC. Table 3 summarizes the status of Year #2 tasks. Details are given below.

ICESat OPERATIONAL ORBIT DETERMINATION AND COMMAND ATTITUDE GENERATION TIMELINE: Task *ISPS Y2T1*

In the operational environment, several tasks must be completed before the command attitude target tables are generated. The time needed to complete these tasks will set the requirement for operational orbit ephemeris predicts. On May 24, 2000 a meeting between CU/CCAR, BATC, and the ICESat Operations Team was held at the Laboratory for Atmospheric and Space Physics (LASP) to define a realistic timeline for the command attitude generation process. Figure 5 shows a schematic diagram of the operational tasks and time required to upload the ICESat target tables. As a result, the operational orbit must be predicted forward, beyond the end of a particular orbit determination period (period over which GPS tracking data are available), by 48 hours.

VERIFICATION OF UT/CSR 8 DAY REPEAT GROUNDTRACK ORBIT USING OPERATIONAL ORBIT DETERMINATION SOFTWARE: Task *ISPS Y2T2*

The reference groundtrack for the mission Verification Phase (8 day repeat track orbit) and the mission Science Phase (182 day repeat track orbit) will be defined by the Science Team and the Precision Orbit Determination (POD) Team at UT/CSR. Since the operational orbit determination system software (MicroCosm) differs from that which will be used by the POD Team, and since the attitude control required to maintain reference groundtrack pointing depends on output from both systems, it was decided that a comparison between the two systems is necessary.

An 8 day repeat track orbit file was generated at UT/CSR and sent to CU/CCAR along with a set of initial conditions and dynamical model specifications. A trajectory for the same period: July 15, 2001 21:00:00 – July 23, 2001 21:00:00 was integrated using MicroCosm. It was initially determined that UT/CSR was using a modified value for the

Table 3
SUMMARY OF ICESat POINTING SUPPORT STUDY GRANT NAG5-7611: TASKS AND STATUS FOR YEAR #2

Task Designation	Description	Status	Description of Additional Related Tasks Completed under Task Designation	Status
ISPS Y2T1	Establish timeline for operational OD and command attitude generation	Complete		
ISPS Y2T2	Verification of the UT/CSR 8 day repeat track orbit using operational OD system software	Complete		
ISPS Y2T3	Recommendations regarding Amery Ice Shelf as a target of opportunity	Complete		
ISPS Y2T4	Modify attitude algorithm to generate quaternions relative to the Inertial TOD frame	Complete		
ISPS Y2T5	Determine number of quaternions required to accommodate variations in topography over regions of interest	Complete	Test using the BATC simulator	In Progress
ISPS Y2T6	Verify 10 m crosstrack pointing error requirement due to orbit prediction errors after 48 hours	In Progress	Study performed with MicroLab-1 s/c at 750 km altitude using dual-frequency GPS observations	Complete
			Formulation for mapping alongtrack and crosstrack predict errors into crosstrack footprint location error	Complete

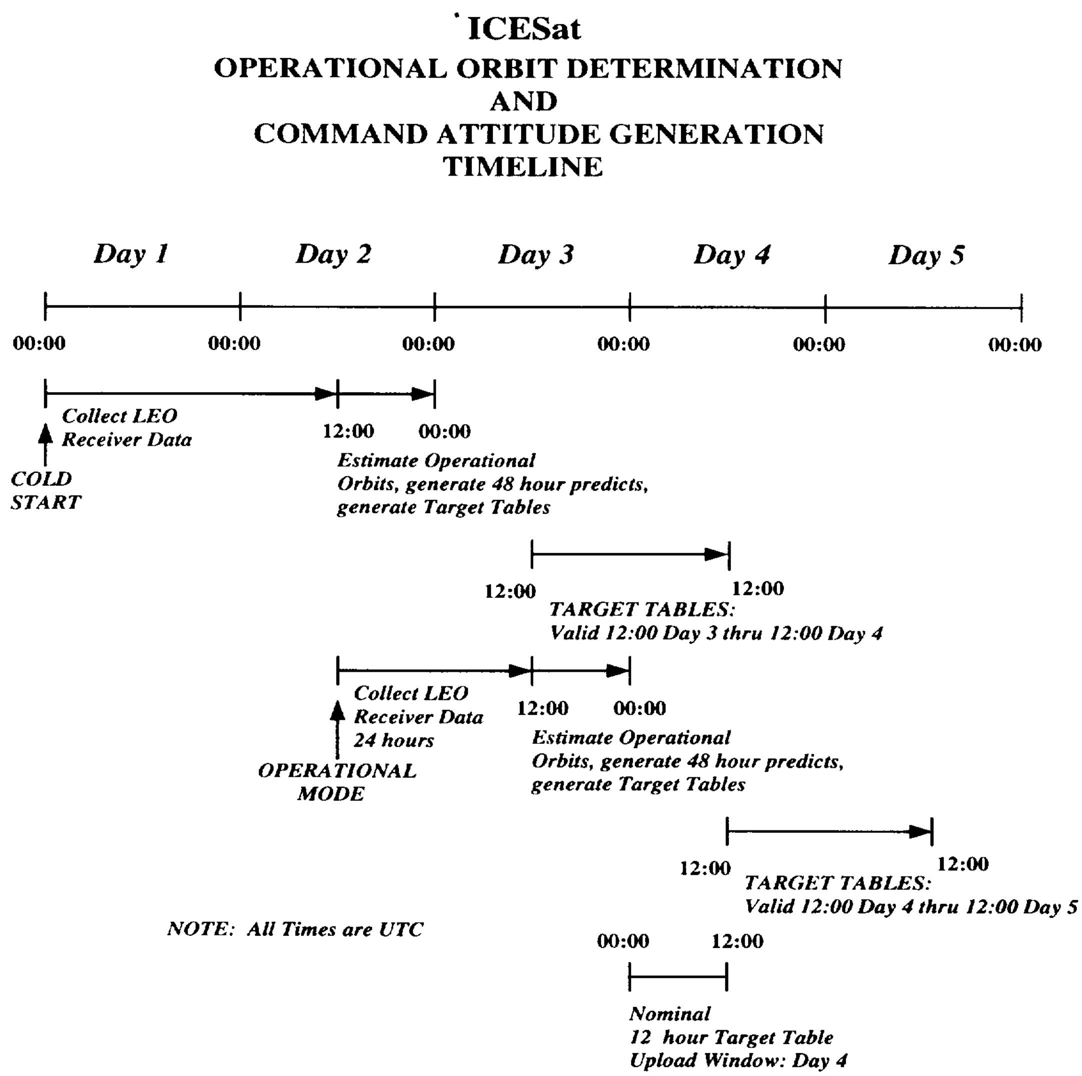


Figure 5. Operational Orbit Determination and Command Attitude Generation Timeline for ICESat.

$C_{2,0}$ term of the JGM-3 gravity field. This term was modified by UT/CSR in order to include the permanent tide. In addition, the epoch time of 21:00:00 on July 15, 2001 was adjusted to account for the difference between Terrestrial Dynamic Time (TDT) and Universal Coordinated Time (UTC). Once these adjustments were made to the MicroCosm software, comparison results showed that the orbits agree to better than 20 cm in the crosstrack direction, just over 2 m in the alongtrack direction, and better than 10 cm in the radial direction over the 8 day period. Figure 6 shows plots of the radial, alongtrack, and crosstrack differences between the trajectory integrated at UT/CSR and the trajectory integrated at CU/CCAR.

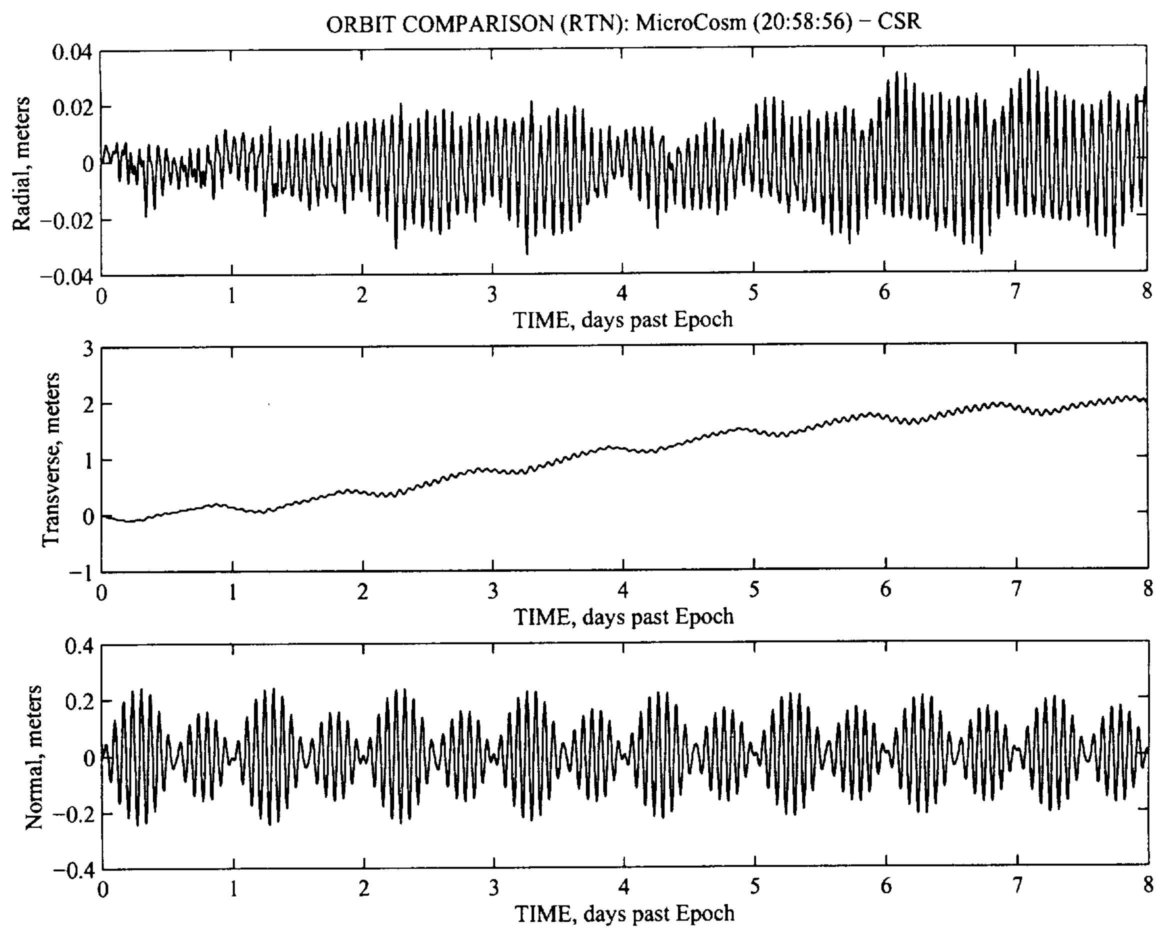


Figure 6. Comparison of 8 day repeat track trajectories integrated using the UT/CSR orbit determination software and using the CU/CCAR operational orbit determination software (MicroCosm) with a -64 sec epoch time correction applied.

AMERY ICE SHELF AS A TARGET OF OPPORTUNITY: Task *ISPS Y2T3*

The Amery Ice Shelf has been of interest to the satellite altimeter community for some time. Comparison of earlier satellite altimeter observations (ERS-1 and ERS-2) with a network of GPS receivers distributed over an area that is 120 km long by 20 km wide was conducted in 1995 for the purpose of ERS-1 and ERS-2 altimeter calibration[3]. In the interest of calibrating the GLAS instrument, the ICESat Science Team proposed using the Amery Ice Shelf as a "target of opportunity" and requested recommendations on targeting this site. The following recommendations have been made for the Amery Ice Shelf and for any target, in general, that deviates from the nominal reference groundtrack:

- At least the nearest ascending and descending pass on the reference groundtrack should be modified to include the target, providing two opportunities to observe the target in a given repeat period; the nearest descending pass nearly parallels the Amery Ice Shelf target.

- The target should be defined by a set of geodetic latitude and longitude coordinate pairs. At least 4 pairs should be used to define the Amery Ice Shelf target; each pair represents a required attitude quaternion.

- Roll angles and associated quaternions may be computed to observe the target during both ascending and descending passes.

- An automated script should be developed for use by the Science Team to read the reference groundtrack, modify it and create a target groundtrack file that includes the targets of opportunity.

A prototype script was developed to modify the reference groundtrack and include the coordinates that define the Amery Ice Shelf. This script currently handles targets that can be defined by either a single set of latitude, longitude coordinates, or by two or more sets of latitude, longitude coordinates. Figures 7 and 8 show the departure from the nominal reference groundtrack required to target the Amery Ice Shelf on ascending and descending passes, respectively.

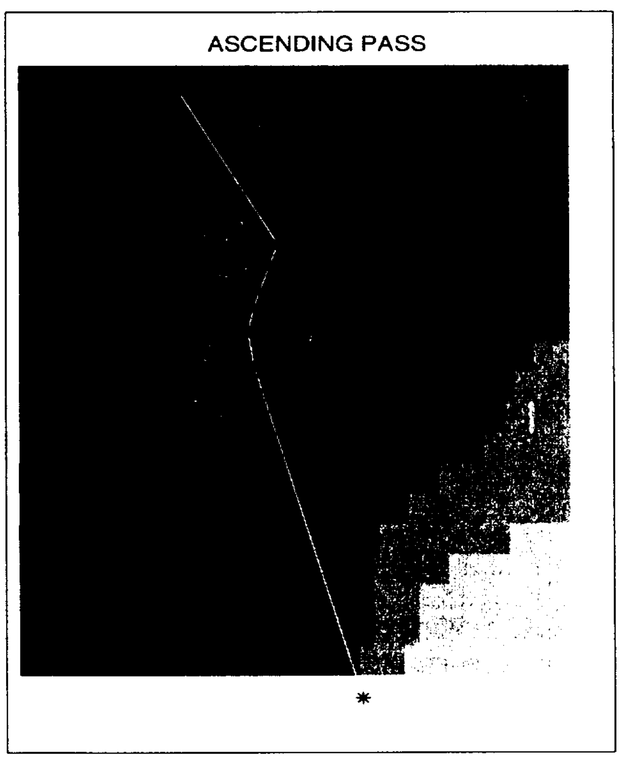


Figure 7. Target track for observing the Amery Ice Shelf on the nearest ascending pass of the reference groundtrack.

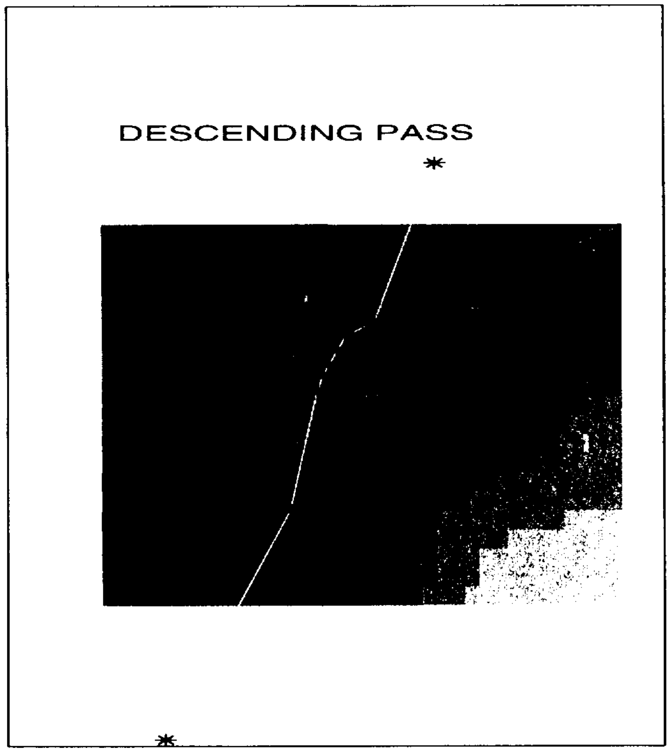


Figure 8. Target track for observing the Amery Ice Shelf on the nearest descending pass of the reference groundtrack.

MODIFICATION OF ATTITUDE CONTROL ALGORITHM TO COMPUTE QUATERNIONS RELATIVE TO THE INERTIAL TRUE OF DATE (TOD) FRAME OF REFERENCE: Task *ISPS Y2T4*

Up to now, the attitude control algorithm for the ICESat spacecraft computed the attitude quaternions relative to the orbit frame of reference. At the request of BATC and in order to be compatible with the ACS onboard the ICESat s/c, quaternions relative to the inertial TOD frame of reference are required. The algorithm was modified to transform the ECEF quaternions to the inertial TOD frame of reference, taking advantage of the precise Earth orientation models used in MicroCosm.

SELECTION OF QUATERNIONS TO ACCOMMODATE VARIATIONS IN TOPOGRAPHY OVER REGIONS OF INTEREST: Task *ISPS Y2T5*

The roll angle correction results shown in figure 4 represent a worst case scenario in terms of crosstrack displacement at the equator between the actual ICESat subsatellite groundtrack and the reference groundtrack, and in terms of the maximum expected inclination deviation due to Luni-Solar perturbations. It is clear that if only the regions of interest are considered, then the maximum roll angle error induced by neglecting topography in the Antarctic region could be as much as 6 – 8 arcsec, resulting in a crosstrack pointing error of approximately 17 – 23 m. For this case, as few as 5 quaternions during an interval of as long as 10 minutes can be used to accommodate variations in topography and drive the roll angle error back down below 3 arcsecs, or equivalently, drive the crosstrack pointing error, due only to topography, down below 10 m. The procedure for selection of upload quaternions is defined as follows:

1. Compute 2 quaternion files: one includes corrections due to topography and the other neglects topography. Each file contains a quaternion at 1-minute time intervals for a desired 48 hour attitude control period.

2. Compute 2 roll angle files: one includes corrections due to topography and the other neglects topography. Each file contains a 1-minute roll angle time interval for the desired 48-hour attitude control period.

3. Compute the roll angle difference time series, which represents the error due to neglecting topography.

4. Test for a roll angle error that exceeds 3 arcsecs when the latitude is above 60° or below -60°.

5. Select 5 equally spaced quaternions during the period for which the roll angle error exceeds 3 arcsecs from the quaternion file that has the topography applied.

6. Choose an evenly distributed set of quaternions for the remaining 25 target table entries, reserving 3 quaternions per orbit for nadir avoidance.

This procedure should be tested using the ICESat s/c attitude simulator at BATC to verify that the onboard maneuver profiler does not induce additional crosstrack pointing errors in going from one quaternion to the next over the regions of interest.

VERIFICATION OF 10-METER CROSSTRACK ORBIT PREDICTION ERROR REQUIREMENT FOR A 48 HOUR PREDICT PERIOD: Task *ISPS Y2T6*

The ability to accurately predict the orbit ephemeris for 48 hours following a given 24 hour orbit determination period is a critical aspect of attitude control for the ICESat s/c. The project has allocated 10 meters of the crosstrack pointing error for orbit prediction error in the crosstrack direction.

A study was performed using dual-frequency GPS tracking observations from the MicroLab-1 s/c during February 1997. Three days of dual-frequency GPS orbits were computed using MicroCosm. These orbits have been verified through internal overlap comparisons and external orbit comparisons. The accuracy is estimated to be approximately 30 cm in total position[4]. The orbit determination solution was computed over the first 12 hours of this 72-hour period and integrated forward 48 hours beyond the end of the orbit fit period. Figure 9 shows the comparison between the predicted orbits and the dual-frequency precise orbits over a 60-hour period (12 hours GPS tracking, 48 hour predict integration). Here, the crosstrack orbit prediction error maps directly into the crosstrack pointing error for the GLAS altimeter and amounts to just over 5 meters. It was originally thought that this would be the only prediction error source. Upon further study, it is clear that alongtrack orbit prediction errors map into the crosstrack pointing error as well due to Earth rotation beneath the satellite. Figure 10 shows a schematic diagram of the mapping of alongtrack and crosstrack prediction errors into the crosstrack pointing error. The value, Δ, represents the total crosstrack pointing error due to both alongtrack and crosstrack orbit prediction errors. The values δ_{at} and δ_{ct} represent the alongtrack and crosstrack orbit prediction error, respectively, and $v_{s/c}$ is the velocity of the s/c. The values $r_{\oplus}$ and $\dot{\vartheta}_{\oplus}$ represent the mean equatorial radius and angular velocity of the Earth, respectively, and λ is the latitude of the subsatellite groundtrack location. As the latitude increases, the alongtrack error becomes less important. However, an alongtrack error of 300 m at 60° latitude will induce a crosstrack pointing error of approximately 9.9 m. Figures 11 and 12 show the absolute crosstrack targeting error and the root-sum-square (RSS) of the alongtrack and crosstrack prediction errors mapped into crosstrack direction, respectively.

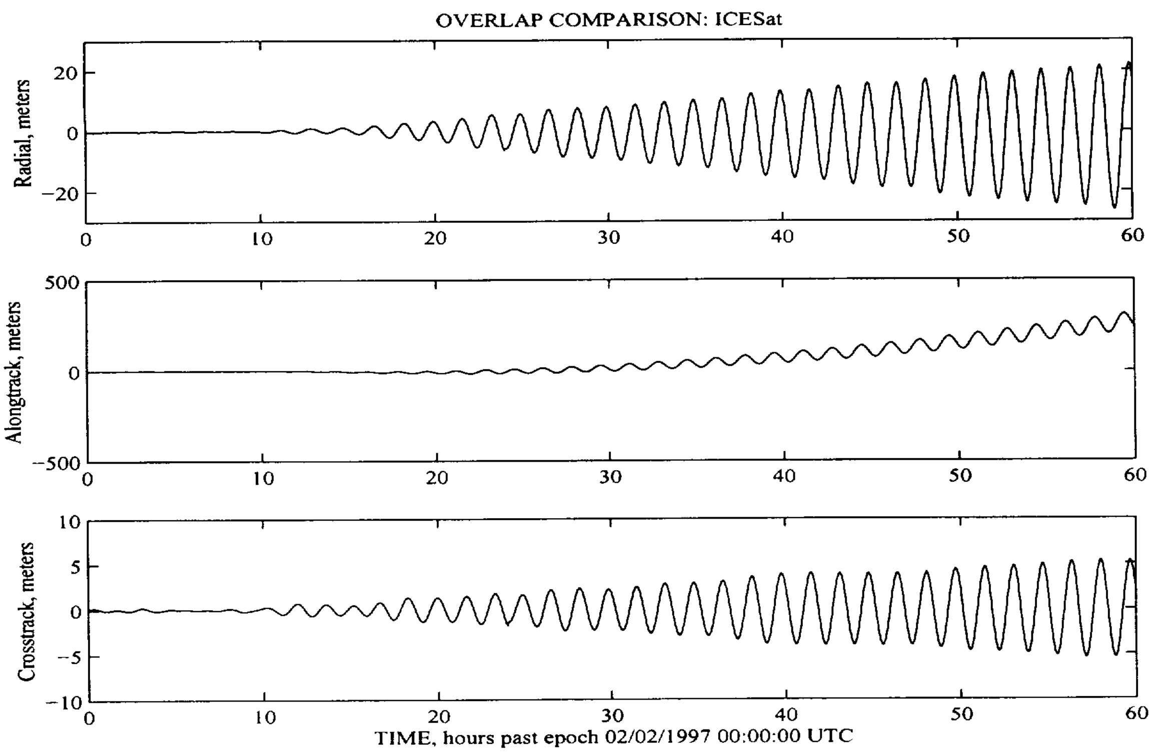
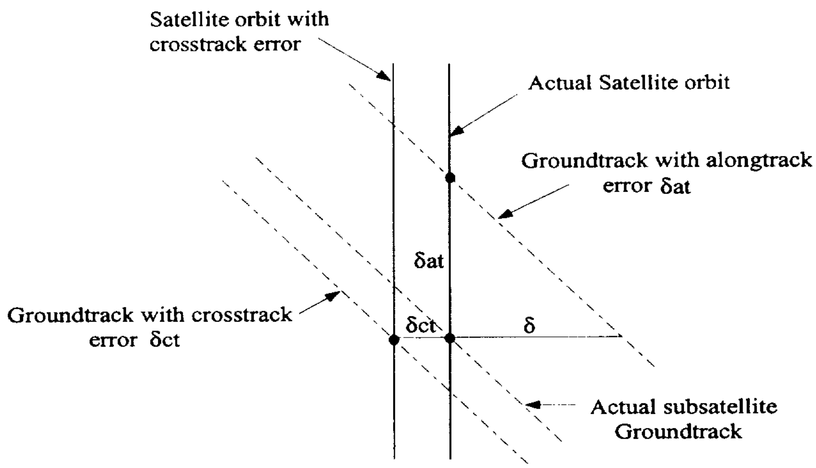


Figure 9. 48 hour orbit prediction error for the MicroLab-1 s/c during 02/02/1997 – 02/04/1997: 750 km altitude and 70° inclination during solar minimum.

MAPPING OF ALONGTRACK AND CROSSTRACK PREDICTION ERRORS INTO CROSSTRACK POINTING ERROR



$$\delta = \delta at\ [r_{\oplus}(\dot{\vartheta}_{\oplus}/v_{s/c})\cos(\lambda)]$$

$$\Delta = \delta + \delta ct \equiv \text{Crosstrack (orbit normal) Pointing Error}$$

Figure 10. Schematic diagram of crosstrack targeting error due to both alongtrack and crosstrack orbit prediction errors.

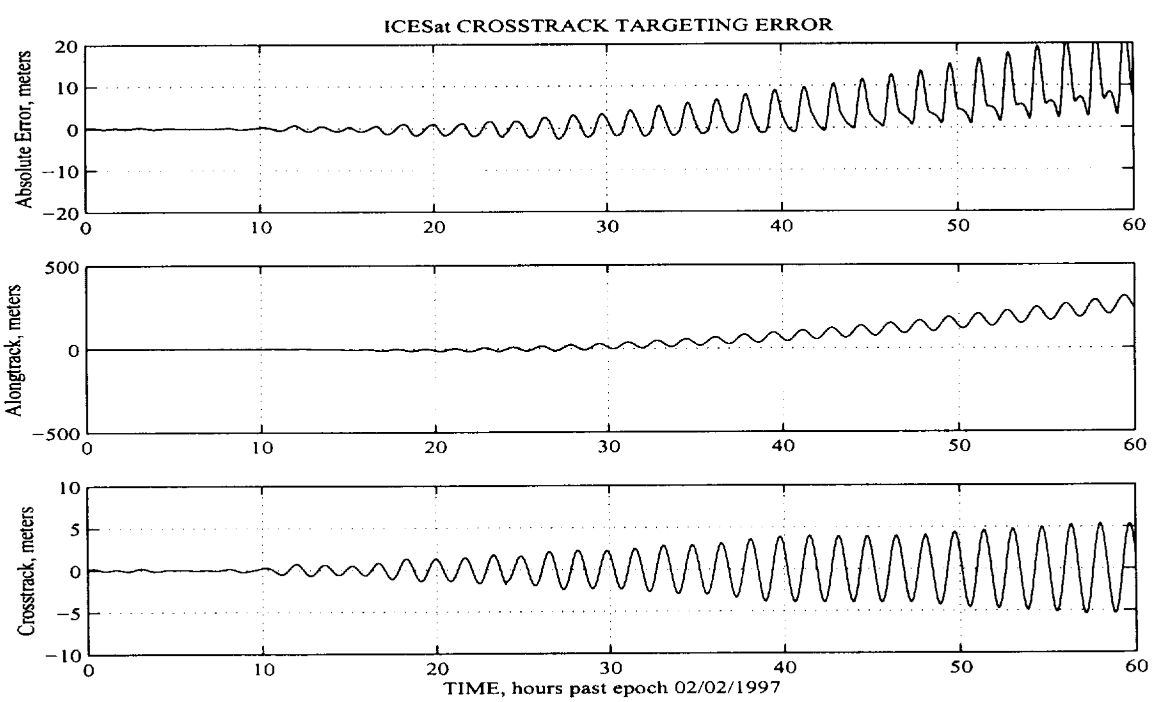


Figure 11. Absolute ICESat crosstrack targeting error due to alongtrack and crosstrack orbit prediction errors.

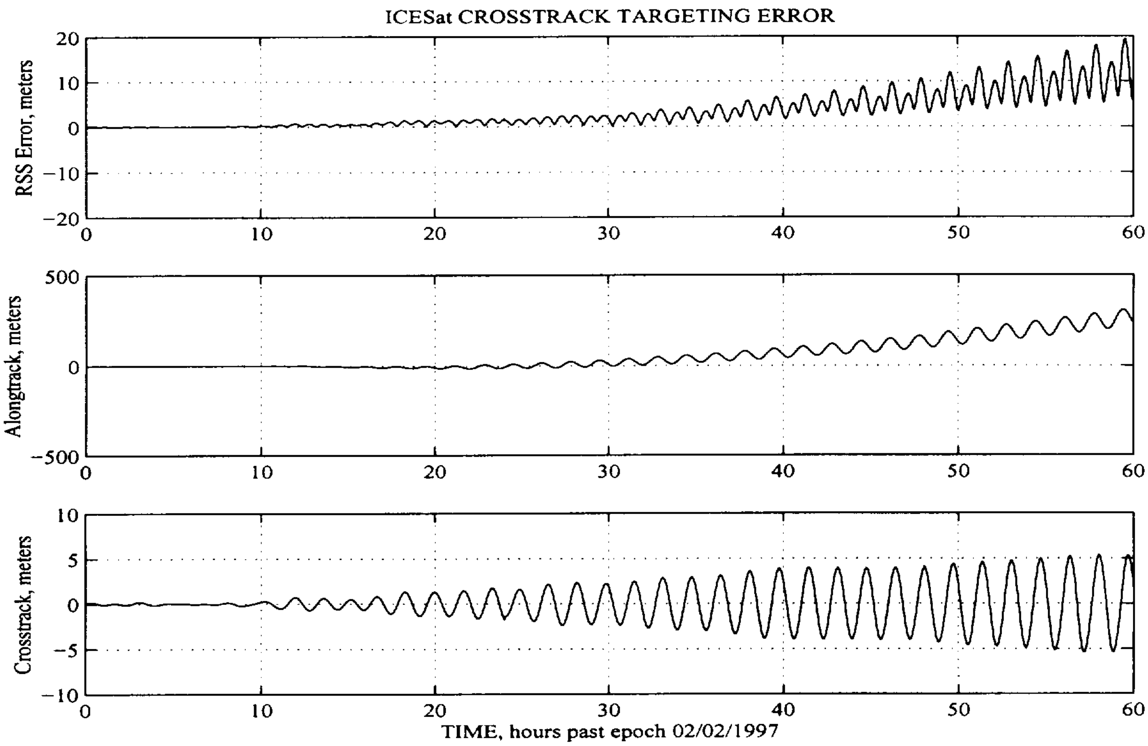


Figure 12. Root-sum-square (RSS) ICESat crosstrack targeting error due to alongtrack and crosstrack orbit prediction errors.

The results shown in figures 11 and 12 indicate that the 10 m crosstrack pointing error requirement is exceeded after approximately 30 hours when the alongtrack and crosstrack contributions are summed; this requirement is exceeded after approximately 36 hours when the alongtrack and crosstrack contributions are summed in quadrature. Two important points must be made: 1) the mean altitude of the satellite used in this study is 750 km, approximately 150 km higher than the orbit proposed for ICESat and 2) The period over which this study was conducted: February 1997, was a period of benign solar activity. ICESat will be operated during a period of increased solar activity. Both the altitude of ICESat and the increased solar activity will degrade the ability to predict the position of ICESat out 48 hours, since alongtrack prediction errors are driven by atmospheric drag modeling errors. In the case of ICESat, the mapping of the alongtrack orbit error into the crosstrack pointing will be the dominant error source.

SUMMARY: ICESat POINTING SUPPORT STUDY, NAG5-7611: YEAR #2

Several critical issues, pertaining to attitude control of the ICESat spacecraft for the purpose of maintained reference groundtrack pointing, were addressed during Year #2. CU/CCAR, BATC, and the Operations Team at LASP cooperatively established a timeline for command attitude generation. Based upon this timeline, preliminary orbit prediction error studies were performed and demonstrated that the crosstrack footprint location error requirement of 10 m due to orbit prediction errors (alongtrack and crosstrack) cannot be achieved at an altitude of 150 km higher than the ICESat altitude. In addition, the maximum allowable alongtrack error assuming no crosstrack error is shown to be 300 m at 60° latitude; beyond that the 10 m crosstrack footprint location error requirement is exceeded.

In order to demonstrate that the operational software could duplicate UT/CSR results, an 8 day repeat track trajectory was integrated using the operational orbit determination software and was compared to the same trajectory integrated at UT/CSR. A few systematic differences were identified and corrected as a result of that comparison.

Over the course of year #2, CU/CCAR provided recommendations to the Science Team on using the Amery Ice Shelf as a target of opportunity. A prototype script was developed to modify the reference groundtrack and target the Amery Ice Shelf. This script was later generalized to handle multiple targets of opportunity.

Finally, it was decided that as few as 5 quaternions could be used over the Antarctic region to accommodate variations in topography when the roll angle correction exceeds 3 arcsec, equivalent to a crosstrack footprint location error of approximately 8 meters. A procedure has been recommended for this and should be tested using the ICESat attitude simulator at BATC to ensure that the maneuver profiler does not induce any unexpected pointing errors when transitioning from one orientation to the next.

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